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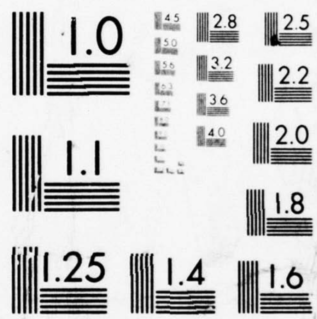

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GUIDELINES FOR MAKING TRADEOFFS: THE SPECIAL ROLE OF TECHNICAL PERFORMANCE MEASUREMENT STUDY REPORT

PMC 73-1

William Henry Rasch, Jr.
GS-13 NAVSHIPS

GUIDELINES FOR MAKING TRADEOFFS: THE SPECIAL ROLE OF TECHNICAL PERFORMANCE MEASUREMENT

An Executive Summary
of a
Study Report
by

William Henry Rasch, Jr.
GS-13 NAVSHIPS

May 1973

Defense Systems Management School
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SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

STUDY TITLE: GUIDELINES FOR MAKING TRADEOFFS: THE SPECIAL ROLE OF TECHNICAL PERFORMANCE MEASUREMENT

STUDY PROBLEM/QUESTION: To describe the general nature of trade-offs made during the various phases of acquisition, to explain Technical Performance Measurement (TPM), and to provide guidelines for using the outputs of TPM in trade-offs studies.

STUDY REPORT ABSTRACT:

TPM began emerging as a system requirement in 1967. It was introduced formally by MIL-STD-499 (AFSC) dated July 17, 1969. Since that time TPM has proven to be a useful tool of systems engineering management in the Air Force and in NAVORD. It is considered desirable, therefore to provide guidance applicable to performance measurement factors pertinent to ship acquisitions, and, also, criteria for using TPM outputs and conducting trade-offs necessary to develop practical and effective ship design solutions. This report describes the general nature of trade-offs which can be made during each phase of a ship acquisition project, explains the techniques of TPM, and provides guidelines for using the outputs of TPM in trade-off studies.

Student, Rank Service	Class	Date
William H. Rasch, GS-13, NAVSHIPS	73-1	May 1973

EXECUTIVE SUMMARY

The "Trade-off" is a means for examining the interrelationships between various performance, schedule, and cost parameters to decide whether or not to improve one element, usually at the expense of another, to maximize system effectiveness and/or the probability of mission success. It is desirable, therefore, to provide guidance to assure that trade-offs are properly made, especially in the performance area; to quantify the likelihood of meeting or exceeding performance requirements; and to assure that changes in the likelihood of meeting these requirements can be tracked. This quantification and tracking process is called Technical Performance Measurement (TPM). Its' purpose is to identify areas of potential difficulty early enough for corrective action or possible trade-off.

TPM began emerging as a system requirement in 1967. It was introduced formally by MIL-STD-499 (reference (1) of the bibliography). Since that time TPM has proven to be a useful tool for use by systems engineering management in the Air Force. It has also been proven to be a useful tool in certain projects of the Navy, the AEGIS project for one. It is considered desirable, therefore, to provide guidance applicable to performance measurement factors pertinent to ship acquisitions and, also, criteria for using TPM outputs and conducting trade-offs necessary to develop practical and effective ship design solutions.

This report describes the general nature of trade-offs which can be made during each phase of a ship acquisition project, explains the techniques of TPM, and provides a methodology for using the outputs of TPM in trade-off studies.

The material for this study was obtained by researching the literature on systems engineering, especially TPM, and by interviewing knowledgeable individuals in NAVSHIPS, NAVORD, and the Defense Systems Management School.

GUIDELINES FOR MAKING TRADEOFFS: THE SPECIAL ROLE OF TECHNICAL PERFORMANCE MEASUREMENT

STUDY REPORT

Presented to the Faculty

of the

Defense Systems Management School

in Partial Fulfillment of the

Program Management Course

Class 73-1

by

William Henry Rasch, Jr.
GS-13 NAVSHIPS

May 1973

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Hoffmann also listened to my decision briefing which addressed system engineering trade-offs.

Contents

GUIDELINES FOR MAKING TRADEOFFS: THE SPECIAL ROLE OF TECHNICAL PERFORMANCE MEASUREMENT*

1. Introduction

According to reference (2), the techniques of systems performance effectiveness have evolved from endeavors to answer the question ... "How is effective systems engineering performed in a real-world environment?" These endeavors have been coupled to the life cycle costing concept because this concept extends the horizons of the systems engineering effort beyond the conceptual and development phases and makes operational and support concepts and cost data a necessary input. Thus, designated Project Managers impose cost and schedule constraints on systems engineering management as well as the technical constraints reflected in operational requirements. Other inputs cover the Project Management or user estimate of value which is placed on missions and tasks to be performed by the systems being developed, and historical data or feedback related to problems of failure, repair, accident, etc.

Systems engineering then must take these inputs, design a ship, and, simultaneously, perform effectiveness analysis.

In these analyses, approaches/alternatives are varied, analyzed, and optimized until an output results which is a measure of the extent to which the ship system may be expected to satisfy user requirements at a certain cost. In other words, the life cycle of any ship includes a continuing series of compromises and trade-offs. They occur in the early stages of the life cycle and continue through engineering development, acquisition, deployment, maintenance, and modification until the ultimate trade-off decision to discard and replace with a higher performance more cost-effective system is made. The principal differences in these trade-offs concern the relative values assigned and the applicability, from phase to phase, of the large number of variables amenable to trade-off. Naval ships, of all major weapon systems, present the most complex problem in achieving meaningful trade-off decisions. A naval ship is a multi-purpose system whose active life usually exceeds the life span of contributing shipborne systems by a factor of two or three. Thus, trade-offs and optimizations of design cannot be done intuitively by the designers with the various factors being weighted by personal experience. Instead, all technical and cost factors as well as development time must be identified and defined, and the trade-off justified and documented in suitable form.

The guidelines presented herein are intended to enhance the technical performance measurement and trade-off processes by specifying trade-off items for consideration at various

stages of the life cycle, by specifying detailed measurement procedures, and by showing how the outputs can be used in trade studies.

2. The Nature of Trade-Offs During the Ship Life Cycle

Conceptual Effort/Preliminary Design. Trade-offs conducted at this stage of development concern functional capability at the highest level of functional indenture, that is, trading-off among the various types of propulsion systems, sonar systems, or weapon systems as system functional requirements or system performance parameters are varied to obtain acceptable design solutions. For example, the constraint posed by the reliability of a prime service-approved shipborne system candidate may cause a trade-off to a shipborne system with a higher reliability. There might also be trade-offs to save weight, or, trade-offs resulting from model tests of various hull forms. The results of such model tests serve to check and improve the accuracy of estimates of resistance, speed, power and maneuverability. Self-propulsion tests may be conducted to determine the best set of propellers and to check the actual shaft horsepower that will be required to drive the ship at cruising and top speeds. Such model tests might even run beyond the allotted time assigned to conceptual effort or preliminary design.

System Contract Design (Validation). During this stage, attention is directed toward the more detailed aspects of individual systems required to fulfill requirements. As design

progresses toward the Total Ship Allocated (Functions) Baseline, the primary trade-off area shifts to such things as: the signal parameter; the details of form, fit, and arrangement; the environmental aspects; weapons and ammunition handling; piping; ventilation and air conditioning; weights; stability; etc. Every element of the conceptual development or preliminary design is reviewed, checked and refined. Whenever the effect of going into greater detail dictates, necessary changes or trade-offs are made. Engineering feedback on such things as boilers, turbines, machinery, etc., is especially important at this stage so that problems with these areas can be eliminated in new designs.

Detail Design and Construction. During this stage a shipbuilder and/or a design agent develop the thousands of detail drawings necessary to build the ship. Some drawings, such as overall system arrangements may require change or trade-offs as necessary to meet new needs, correct an incompatibility, etc. As time goes on, however, the latitude for practical change or trade-off, to incorporate improvement, narrows. Cost and delay are very real considerations at this stage because shipbuilders and design agents are obligated by contract, and changes not only delay material work, but also involves the slow process of legal approval, acceptance, and compensation.

Deployment and Disposal. The ship as a total system can be expected to have a longer active life than the component

threat-countering or attack systems, support systems, subsystems, and equipment. As the threat changes and technology provides improvements, continuing analysis is required to ensure that the total ship system capability is optimized at all times. As improved component systems become available, each is considered with respect to: the degree of capability enhancement attainable; compatibility with other component systems to be retained in the ship; logistic effects; improvements in fleet standardization; and costs to procure and install with the relationship relative to the remaining effective ship life. Decisions regarding the degree of alteration, modernization or conversion to be accomplished are recorded in Navy planning documents such as the Class Improvement Plan (CIP). When analysis or inspection has established that the ship should be disposed of the decision is recorded and the rationale involved documented.

3. Introduction to Technical Performance Measurement (TPM)

According to reference (1): "TPM is the continuing demonstration and prediction of the degree of actual or anticipated achievement of selected technical goals or objectives of a system or part thereof, together with causal analysis of the variance between achievement and objective. The purpose of TPM is to permit appropriate managers to take timely action on indicated problems." Reference (3) states that TPM is the function by which the status of system performance characteristics

are determined during development, using calculations or measurements of system element design parameters. Reference (3) further states that the total function consists of parameter modeling, planning, measuring, evaluating and reporting, and, it uses normal engineering and management activities and techniques to the greatest extent possible.

TPM is not really a mystery, as evidenced by the many references on the subject in the bibliography. The steps in setting up a system will be described in this paper, however, if any reader is serious about the subject, and wants to set up a system he is urged to read references (1), (3), (4), (6) and (8). Although the objective is the same, there are many ramifications. This paper describes a system based on subjective probability distributions. Such a system is described in reference (4) and is most advantageous when hardware does not exist, that is, hardware which can be tested, or measured, to determine status of performance characteristics. Indeed, each new ship acquisition, conversion, or fleet modernization project should plan and execute a TPM effort that is tailored to meet specific project needs. The effort should be continuous and should constitute the tracking of technical achievement to date versus a forecast of expected achievement and an analysis of any variations. Such a system will contribute to trade studies, as specifically required to support the decision needs of the ship systems engineering effort.

The steps in measuring and tracking technical performance are:

a. Determine the performance variables essential for technical success and establish performance functions or equations which relate performance variables (outputs) to design variables (inputs). Performance equations which specify relationships between design variables (inputs) and performance variables of interest (outputs) may be selected from the Technical Manual of the Naval Ship Systems Command (NAVSHIPS) or otherwise developed for use in the TPM program. Typical ship performance variables are: V, speed in knots (nautical miles per hour); R, range in nautical miles; and E, endurance in hours. Ship design variables are: L, length in feet; W, displacement in long tons (2240 pounds per ton); P, installed shaft horsepower; and F, weight of fuel in long tons. Typical ship performance equations are:

(1) Speed

$$V = K_o \times \left[\frac{\overline{PC}}{\overline{DC}} \right]^{1/3} \times \left(\frac{P}{(LW)^{1/6}} \right)^{1/3}$$

Where, $\overline{PC}$ is a propulsive coefficient and $\overline{DC}$ is a draft coefficient. These coefficients vary depending on the ship type. K_o is a constant.

(2) Range

$$R = K_1 \times \frac{F}{P^{2/3}} \times \left[\frac{\overline{PC}}{\overline{DC}}\right]^{1/3} \times \frac{1}{(LW)^{1/6} \times \overline{OSFC}}$$

Where, $\overline{OSFC}$ depends on power plant type and represents overall specific fuel consumption in pounds per installed shaft horsepower per hour. K_1 is a constant.

(3) Endurance

$$E = K_2 \times \frac{F}{P} \times \frac{1}{\overline{OSFC}}$$

Where, K_2 is a constant.

The foregoing example performance equations specify a relationship between design variables and some performance variable of interest. This relationship may be known from first principles, inferred from experimental data, or contain elements of each. Some of the design variables may be known exactly. In other cases, knowledge may be much less certain. For example, one might have a technical objective to develop a new power plant. Hence, $\overline{OSFC}$ in equations (2) and (3) would not be known exactly. In any case, the ultimate objective of developing such relationships is to quantify the likelihood of meeting or exceeding performance specifications in time to make trade-offs, or take corrective action.

b. Develop subjective probability distributions for the design variables, the inputs, by making inquiries of design

personnel. According to reference (4), the interview technique systematically draws from a man's memory of his past experiences (including test results) the information necessary to reconstruct a range of expected design values (inputs), and the associated probabilities. For each design variable, estimate ranges of values and probabilities of occurrence over the range. For example:

Design Variable	Range	Probability
$\overline{\text{OSFC}}$	.50 - .55	.3
	.55 - .60	.5
	.60 - .65	.2

c. Use appropriate techniques (e.g., simulation) to determine the likelihood of meeting technical objectives, or of obtaining desired performance (e.g., speed, range, endurance, etc.). A sample array for V, R, and E, and associated probabilities, p(V), p(R), p(E), is given below:

PROBABILITY DISTRIBUTIONS FOR SYSTEM PERFORMANCE CHARACTERISTICS (OUTPUTS) IN A HYPOTHETICAL SHIP DEVELOPMENT PROJECT

V (knots)	16	17	18	19	20
p(V)	.15	.20	.45	.10	.10
R (miles)	4000	5000	6000	7000	8000
p(R)	.10	.20	.40	.25	.05
E (hours)	3800	4000	4300	4400	4500
p(E)	.25	.35	.20	.10	.10

d. Track changes in the likelihood of meeting performance objectives. An example of this tracking process is given for ship speed in Appendix A, Tables I and II and Figures 1 and 2, pages A-1 and A-2.

An analogous system was described by F. S. TIMSON, in reference (4). Other sample output reports are also shown on pages A-3, 4 and 5 in Appendix A, Figures 3, 4, and 5. These sample reports were taken from references (3), (6) and (7) respectively.

4. Guidelines for implementing TPM

Reference (8) contains an excellent summary of TPM implementation requirements. According to reference (8): "When you boil it all down the requirements contained in MIL-STD-499 concerning TPM are essentially to plan everything and then to perform in accordance with the plans. Three basic topics are evident. The first is planning itself. The parameters to be measured, to what standard, when, under what conditions, the values expected, who is responsible, etc., are all to be planned in detail and documented. Secondly, the evaluation efforts, obtaining observed values, preparing predicted values, and identifying variance at levels below reporting elements are then all performed in accordance with the TPM plan. In fact all efforts to compare performance with specified values are to be included in the TPM plan. Likewise the reporting routines, variance corrective action process, the determination of the impact of out-of-tolerance conditions and follow-up management actions are all conducted in accordance with the same TPM plan. Certain key elements are necessary in the implementation of a TPM program. These elements essentially in their order of occurrence are:

-- Selection of Parameters and Detail Documentation

-- TPM Models

-- Parameter Profiles

-- TPM Plan

-- Organizational Participation

-- Reports and Formats

-- Analysis, Predictions, and Impacts"

This paper does not address all of the areas necessary for TPM implementation. Those individuals who are really interested should read reference (8) and other more detailed references on the subject. This paper does address those implementation areas which are considered most important from a Ship Acquisition Project Management point of view. TPM math models, reports and formats have already been addressed. TPM plans and organizational participation will not be addressed at all because plans must be tailored and participants change so frequently. Suffice to say that plans and organizational responsibilities must be spelled out. Now let's look at selection of parameters; parameter profiles, and; analysis, predictions, and impacts.

a. Selection of Parameters. According to reference (8), all parts of a Work Breakdown Structure (WBS) which have cost and schedule factors assigned may not, in fact the majority probably will not, have TPM parameters associated with each. In practice, TPM parameters should be selected for one or more of the following reasons: mission/task critical; state-of-the-art

critical; and/or will be incentive related or be contractually required. All parameters must be measureable. A mission/task critical parameter, for example, may be ship speed or range or endurance, or it may be associated with a subsystem such as a radar. Important radar performance parameters are range and resolution. In any case, the parameter selected for measurement should be important and difficult to achieve. We might say that the degree of technical risk will be medium-to-high.

In ship acquisition projects, the selection of performance parameters should begin during the conceptual effort. In fact, where shipborne systems are being developed by other system commands, "measurement" should begin during the ship conceptual effort. This can be accomplished by including appropriate requirements in Ship Project Directives. The AEGIS missile system project, for example is already implementing a comprehensive TPM system. Normally, ship related parameters should be selected during the contract design or validation phase. It is extremely important to have "potential difficulty" information, especially on GFE, early enough to institute a trade-off and fallback to more mature equipment.

Up to the present time a TPM system has not been in use in Ship Acquisition Project Management Offices. A more efficient, more formal, system is considered desireable, however. This is especially true with respect to complex shipborne systems. It would be wise, I think, for a Ship Acquisition Project

Manager to require that participating managers provide current information on how they are doing technically. To repeat, this is especially important in GFE areas that exhibit high risk. Shipbuilders may also be required to provide information on selected parameters by a contract clause such as the following: "The contractor shall prepare and submit for approval a list of TPM parameters consistent with the detail specifications, and measure and report thereon monthly in accordance with Contract Data Requirements List Data Item __, Technical Performance Measurement Report". A sample Data Item Description, DD Form 1664. "TPM Report" and associated sample reports are included in Appendix A, pages A-6 through A-14.

b. Parameter Profiles. The sample Data Item Description mentioned above, includes a Figure 2 which is a suggested TPM parameter profile and graphic reporting format. See page A-15. It shows a line for the planned parameter value, and an upper and lower tolerance limit. The lower tolerance limit is the only line which should trigger a variance analysis. A value above the upper limit indicates that specification requirements will be exceeded and no variance analysis should be required. Unless an interface will be affected, therefore, it is suggested that only the lower limit be shown. In any case, profiles are necessary and, according to reference (8), serve the following functions:

- Give a visual presentation of progress history and program goals
- Relate time, performance and analysis/test events on one page
- Provide the criteria for variance reporting during the life cycle of the parameter, and
- Provides a mechanism for presenting predictions and planned corrective action results.

Here again, the existence of a large tolerance between the minimum profile and the required value line tends to indicate a greater uncertainty in attaining parameter performance, and will tend to focus attention on a probable technical risk. What it says simply is, if I do worse than this minimum performance at the particular time shown, I probably can't get there from here; therefore, some change of plan or corrective action is called for.

c. <u>Analysis, Prediction and Impacts</u>. According to reference (8): "The ground rules presently proposed for reporting a variance is, whenever a planned evaluation or test result falls below the minimum parameter profile, a variance exists and the variance analysis report is required. Engineering personnel responsible for the technical parameter in variance must prepare the analysis, the corrective action plan, and the revised predicted value of the parameter." In fact, knowledgeable personnel should provide trade-off recommendations, if necessary,

to correct a variance.

The rest of this paper describes some of the factors that must be considered in trade-off studies.

5. Factors to be Considered in Using TPM Outputs in Tradeoffs.

Trade-offs are used to obtain a practical balance between cost, schedules, and performance of systems. In this context, cost includes all costs of acquisition and ownership; performance includes all factors influencing effectiveness in operational use such as reliability and maintainability; and system includes all hardware and other required items such as facilities, personnel, data, training, and equipment.

The weight factor or relative value assigned to various elements and their specific applicability is subject to wide variation. Depending on the particular program, the acceptability of risk, fiscal or political considerations, or personnel ceilings may take precedence over each other at any given time. However, the fundamental considerations are that the approved choice must be financially acceptable, be technically feasible and have the required performance capability, be militarily useful, and be available in a timely manner.

a. Costs and Benefits. Whenever the output of a TPM system triggers a trade-off study, costs and benefits will always be driving forces. Reference (9) includes pertinent guidelines applicable to such considerations. These guidelines are summarized in the following paragraphs.

Exceptions to cost-benefit analysis, as well as examples of investment proposals to which such analysis apply, should be as specified in SECNAVINST 7000.14 of 30 Jan 1970. In general, cost-benefit analysis should be performed when the specific objective is to identify one of the following:

• The alternative which is expected to produce the needed benefits or effectiveness for a given cost level. (The Equal Cost Criterion)

• The least costly alternative of several equally effective ways to achieve an objective. (The Equal Effectiveness Criterion)

• The relative cost of various alternatives and the effectiveness that can be provided so a judgment can be made as to whether increased effectiveness is worth additional cost. (The Unequal Cost/Unequal Effectiveness Criterion)

The definitions, maximum economic lives, the discount rate, and the discount tables associated with cost-benefit analysis are to be as specified in SECNAVINST 7000.14 of 30 Jan 1970.

•• The Equal Cost Criterion. When benefits are a determining factor, the alternative which yields the needed benefits (or effectiveness) for a given level of cost should be preferred. This criterion should also apply to no-cost changes. Under this criterion a detailed investigation of benefits should be undertaken to determine which alternative provides the needed level of benefits best.

When use values are in effect (i.e., benefits not expressed in dollars) benefits associated with the status-quo and all options/alternatives may be either listed or scored. Assuming equal risk, the option/alternative with the greatest benefits or the highest score is preferred. See the paragraph following dealing with unequal cost/unequal effectiveness for guidelines appropriate to situations of unequal risk.

Usually, market values do not apply (i.e., benefits expressed in dollars); however, when they do, it is necessary to estimate the discounted cash flow income or revenue resulting from the specified investment. This requires a prediction of future volume/demand at a specified unit price. At best, this requires skill, experience, and luck because there is no satisfactory way to predict the future. It is recommended that statistical data on past revenues be collected, or that a marketing survey be conducted to obtain sample data. Once this data is collected, it should be subjected to statistical analysis to obtain predictions (at the 95% confidence level) of future income. Here again, assuming equal risk, the option/alternative which promises the highest income or revenue is preferred.

•• <u>The Equal Effectiveness Criterion</u>. When alternative investment proposals for achieving a given objective all provide a specified level of benefits, the alternative with the lowest discounted cost is preferred (assuming equal risk).

This criterion is called the "equal effectiveness" criterion. When this criterion is used it is not really necessary to conduct a detailed investigation of benefits because it is assumed all options/alternatives will yield the same benefits. It is necessary to conduct a detailed investigation of costs, especially life cycle costs, to justify selection of an option or alternative. In fact, the "savings" resulting from the lowest estimated life cycle cost may be sufficient justification. Unless contracts or cost estimates for budgets are involved, alternatives may be evaluated/justified on a relative cost basis, as long as estimates are comparatively correct, and as long as absolute estimates cannot be developed by extrapolating the cost of similar previously developed systems. When the new system, or option/alternative, is radically different from the previous one (and this is becoming increasingly common) absolute cost estimates may be nothing more than educated guesses. When contracts are involved, it is necessary to get an absolute estimate of cost from the contractor before an evaluation of the impact of a change can be made.

In any case, costs must be compared to a common base. Where systems are in existence, total costs may not include developmental costs but only procurement and maintenance costs over the comparative time period. Where systems under development are in competition with existing systems, the cost basis utilized must be such as to ensure that comparability is maintained.

Where all the competitive alternatives are developmental, total life cycle costs are the preferred basis for comparison. In making estimates, great care must be exercised to ensure that assumptions utilized in assessing costs are realistic. In figuring cost trade-off factors, the relative value of eliminating or retaining optional functions should be considered.

•• The Unequal Cost/Unequal Effectiveness Criterion. Generally, there is no all-purpose criterion for identifying the preferred option/alternative in cases where both benefits and costs are unequal. Project Managers are confronted with a large number of competing, and often equally valid, requirements which they must reconcile. Usually, they are faced with options/alternatives that offer increased benefits at an increase in cost.

Whether market values or use values apply, the ratio of needed level of effectiveness to cost should be used to determine gain per dollar spent. When market values apply, it is necessary to estimate discounted income and costs as indicated in the paragraphs preceding. When use values apply, benefits associated with the status-quo and all options/alternatives should be listed or scored. The percentage change in the options/alternatives from the status-quo may then be computed. Once this is accomplished the decimal equivalent of the percentage change may be added to or subtracted from one, as the case may be, to obtain an expected value of benefits.

The same procedure may then be followed with respect to costs; i.e., estimate the cost of the status-quo and all options/alternatives and then compute the percentage change in the options/alternatives from the status-quo. Once this is accomplished, the decimal equivalent of the percentage change may be added to or subtracted from one, as the case may be, to obtain a "scored" value for costs. This value for costs may then be divided into the value for benefits to obtain a ratio of benefits-to-cost. Assuming equal risk, the option/alternative with the highest score or payoff (P) greater than one is preferred.

When risk is not equal, the option/alternative with the lowest risk and the highest payoff is preferred. It should be obvious, however, that several alternatives may be approximately equivalent even though payoffs and risks are unequal. In this situation the criterion for establishing priorities and/or for selecting an option/alternative is: choose the option/alternative for which the ratio of payoff-to-risk is the highest. For example: an option/alternative with a payoff of 4.1 and a risk of 1.1 is preferred over an option/alternative with a payoff of 4.3 and a risk of 1.2. The ratios of payoff-to-risk are 3.72 and 3.58, respectively. These ratios may be called "Preference Numbers." In the example cited, they indicate that the smaller payoff is preferred to the larger but more variable (higher risk) payoff.

b. Risk. Risk may be defined as the subjective probability of failure to meet requirements or objectives governing technical characteristics, budgeted funding levels, or schedules. Whenever trade studies are being conducted, the degree of risk associated with each alternative should be identified and assessed, and, if a risky alternative is selected, that risk must be controlled. TPM plays a duel role in the risk management process. First, it helps to identify technical risks and second, it helps us to control risk by keeping track of technical progress.

Technical risks may appear when we attempt to introduce features which have not been successfully developed or constructed before. Other causes of technical risk are inadequate definition of operational performance objectives (uncertainties in requirements), insufficient hardware demonstration of GFE, and lack of trained and experienced technical personnel. Because of these situations there is always a chance that performance requirements will not be met, or there will be reliability/maintainability problems, or service approval will be denied, etc.

Technical risks associated with TPM parameters may be assessed qualitatively or quantitatively and may be classified as HIGH, MEDIUM, or LOW, where definitions of HIGH, MEDIUM, and LOW must be generally understood and accepted by everyone associated with a particular project. The degree of risk may be

assessed based on the variance around a TPM profile, or it may be assessed based on a lack of resources, for example, a lack of input information, capabilities, or knowledge. The degree of risk may also be quantified by a simple scoring process. For example, a score from 1.0 to 2.0 would signify LOW risk -- a score from 2.1 to 3.9 would signify MEDIUM risk -- and a score from 4.0 to 5.0 would signify HIGH risk. The consequences of failure to achieve a requisite technical characteristic may be expressed by a value which represents an increase in cost. In other words, the consequences of failure to solve a technical problem may be a large cost increase. Such a technical problem may be quantified in risk terms as follows:

$$\begin{bmatrix}\text{High Probability}\\ \text{of Failure}\end{bmatrix} \times \begin{bmatrix}\text{High Cost Impact}\\ \text{of Failure}\end{bmatrix} = \begin{matrix}\text{HIGH}\\ \text{RISK}\end{matrix}$$

$$1 \quad \times \quad 5 \qquad\qquad 5$$

As noted above, TPM may be used as a means of risk control because it will help us monitor technical achievement in design and hardware development in key GFE and in all other areas of a ship

c. <u>Operational and Performance Factors</u>. Operational and performance factors constitute prime areas of consideration when making trade-offs. For example: operational factors to be considered are: -- The basic threat which is the basis for the mission and functional requirements -- mission requirements for each system in terms of the relationship to other systems --

and anticipated deployment considerations, such as number of installations, and operational locations.

With respect to ship performance, trade-offs must be made keeping in mind, for example, the minimum acceptable values of variables such as speed, range, or endurance and other essential aspects of ship system performance. Also, the functional capabilities of shipborne systems, subsystems, or equipments that must be compared and evaluated against the mission requirements comprising the performance envelope must be considered. For example: the functional requirement "conduct surface surveillance" may be satisfied by a relatively simple short range radar system with a Figure of Merit (F.O.M.) given in terms of a Performance Measure (P), the Equipment Operational Readiness (EOR), and cost. The equation is:

$$\text{Cost Effectiveness (F.O.M.)} = \frac{(P) \times (EOR)}{\text{Life Cycle Cost}}$$

Where,

$$P\ (\text{RADAR}) = W_1 \left[\frac{\begin{array}{l}\text{ESTIMATED}\\ \text{SYSTEM}\\ \text{RANGE}\end{array}}{\begin{array}{l}\text{ACCEPTABLE}\\ \text{RANGE}\end{array}} \right] + W_2 \left[\frac{\begin{array}{l}\text{ESTIMATED}\\ \text{SYSTEM}\\ \text{RESOLUTION}\end{array}}{\begin{array}{l}\text{ACCEPTABLE}\\ \text{RESOLUTION}\end{array}} \right]$$

Estimated system range and resolution may be obtained from the TPM system. In any case, the equation is a simple two-dimensional performance vector with weighting factors W_1 and W_2 assigned to indicate the relative importance of the respective dimensions. In effect, these numbers are subjective military worth assessments which can be conveniently divided into

eleven categories (or any number of categories) as defined below and in reference (10).

Weight	Regarding Applicability	Regarding Importance
1.0	Completely Applicable	Extremely Important
0.9	Nearly Always Applicable	Highly Important
0.8	Highly Applicable	Very Important
0.7	Frequently Applicable	Important
0.6	Generally Applicable	Fairly Important
0.5	Probably Applicable	Probably Important
0.4	Moderately Applicable	Some Importance
0.3	Occasionally Applicable	Of Little Importance
0.2	Rarely Applicable	Very Little Importance
0.1	Nearly Always Applicable	Unimportant
0.0	Completely Inapplicable	No Importance Whatever

EOR is the probability that a system will operate satisfactorily throughout an interval of time $(t_1 - t_0) = t$. EOR is discussed in reference (11) and is defined by the following equation:

$$EOR = \frac{e^{-\lambda t}}{1 + \lambda\beta}$$

Where λ = failure rate

β = Mean Down Time

d. Physical Parameters and Limits. Even though TPM only provides outputs in the performance area, physical elements such as size, weight, and service requirements require careful

thought when trade-offs are being considered. For example:

- Weights -- Evaluate weight limits and moment affect.
- Dimensions -- Size and shape, crew space, operator station layout, and maintenance accessibility should be considered.
- Requirements for transport and storage. These requirements include such items as tie downs, pallets, battens and containers.
- Durability and ruggedness factors.
- Special requirements for safety or health including considerations of explosive, mechanical and sociological effects.
- Command and Control Requirements. Evaluate the requirements for support system or equipment inputs necessary for the system under consideration to function properly.
- Vulnerability factors of competing systems including atomic, chemical biological, radiological, electromagnetic radiation, fire, and shock considerations.

e. Reliability. Considerations of reliability are of major concern in system selection. Expressions of reliability for evaluation and comparison between competing systems should be expressed in quantitative terms wherever possible. However, whether the comparison be quantitative or qualitative, the measurements must be to the same criteria for all systems under consideration. To the degree feasible, system reliability should be broken down into the reliability of component subsystems

and equipment. This breakdown will permit ready evaluation of the effect of trade-offs at the subsystem or equipment level.

f. Maintainability. Assessment of maintainability for trade-off purposes should include evaluation of such factors as:

- Level of Maintenance required (ships force, tender, shore based repair facility)
- Ease of component or unit replacement
- Commonality and interchangeability of units
- Automatic test, checkout and fault location features
- Preventive maintenance requirements
- Spare part logistics
- Equipment accessibility

g. System Availability. Evaluation of the reliability and maintainability combination. This evaluation will enable forecasting a system availability at any given time.

h. Personnel Factors. Personnel factors include an assessment of each competing system in the light of manning, skill level, training and human engineering requirements or problems. This estimate also provides an insight into relative system or equipment complexity.

- Manning. Evaluate for each system the manpower required for both operation and maintenance. Items to be considered include: ranks and ratings; job classification; numbers of personnel; and, in cases where alternatives are being considered to replace an operating system,

changes in manning requirements.

- Training. Evaluate requirements for specialized training, prerequisite skills, length of training required, and other similar factors which may affect the timely and optimum utilization of the systems being considered.
- Human Engineering. This area requires evaluation of any man-machine problem inherent to alternatives under consideration.

i. Facilities. Evaluate any requirements for construction, purchase or development of new or different advance base, training, repair, logistic, and/or other facilities or systems in order to support an alternative under consideration. The assessment should also include an evaluation for achieving the objective through modification of existing external facilities or support capabilities.

j. Compatibility. In the development of a ship system as an engineering and functional whole, the compatibility of interfacing threat countering or support systems, subsystems or equipment is of paramount importance. For this reason, and to ensure that no interfacing parameter is inadvertently overlooked, each trade-off analyses should include a separate assessment of all factors which affect compatibility. In the conduct of the compatibility evaluation of competing alternatives, requirements may be disclosed which indicate a requirement for buffers to ensure compatibility. These buffers along with their related

costs must be included in the overall evaluation of that particular alternative.

k. Standardization. The defense standardization program acts as a constraint on the systems engineering effort because it influences the trade-off decisions made during the effort. This influence is felt because the program seeks to control the variety of items required to build and maintain a system. Specific objectives are: (1) identicality in design and hardware to the extent necessary to achieve the optimum in reliability and supportability at least cost, and; (2) maximum utilization of items already supported by the supply system so as to avoid an increase in the range and depth of items to be supported. Thus, during trade-off studies, Project Managers should require systems engineering to identify and exploit opportunities to use interchangeable items for similar functions in order to achieve optimum commonality within their particular systems.

l. Safety. Safety must also be considered during trade-off studies to assure the protection of individuals from injury or death and to prevent damage to or loss of equipment or property. Alternatives under consideration must not violate safety regulations such as those pertaining to classification of explosives for handling purposes, detection and warning systems, etc. Alternatives must also not violate special Project Management needs such as fail-safe, redundancy, crashworthiness,

egress, and rescue and survival procedures.

m. Integrated Logistic Support. The alternative selected during a trade study should reflect the inclusion of reliability, maintainability, personnel, human factors, safety, support equipment, spares, training, and facilities considerations. The alternative should also reflect such things as: who supports what; flow from producers to users; shipboard handling techniques; provisioning recommendations based on usage rates or failures expected per time period and the time ships can be expected to be out of range of support facilities; inventory control procedure recommendations relative to ship schedules and supply centers; recommendations as to the disposition of failed parts; functional module substitution concepts; identification of long lead time equipment; recommendations applicable to training; recommendations applicable to the tactical supply system (e.g., underway replenishment, ship spares, AE spares, transfer of repair parts and weapons or equipment from dockside or barge to ship); recommendations applicable to maintenance echelons (e.g., shipboard, shop, tender, contractor, field engineer, shipyard, factory); and integrated test requirements based on criteria such as fault detection and correction routines for all combat systems electronics shall be run daily, or, expendable ordnance shall not be tested aboard ship, etc.

6. Documenting Trade-Off Studies. Trade-off studies should be described in documents such as Proposed Technical Approaches,

Concept Exploration Reports, Ship Acquisition Plans, Design Histories, TPM reports or trade-off descriptions. Such reports constitute a continuing historical record of all trade-off decisions made and the design/capability/cost alternatives considered during the ship system life cycle. A sample outline of a trade-off description/report is included in Appendix A, page A-16. All of the entries shown are self-explanatory.

7. A Hypothetical Example.

Engineering is responsible for the definition and technical integrity of interfaces. During the ship system design process, system engineers identify and define all the shipborne systems needed to meet functional performance requirements. Interface documentation is developed which initially delineates broad performance descriptions or requirements but which is eventually expanded into detailed interface descriptions reflecting a compatible system. The documentation eventually serves as a basis for Configuration Change Control and Accounting and is used to demonstrate that compatibility does exist and that all appropriate interface characteristics have been examined. Suffice to say that engineering interfaces provide fertile ground for selecting parameters for technical performance measurement.

During ship system design, performance requirements may be allocated to the various functional areas or Work Breakdown Structure (WBS) elements in terms of interface constraints,

that is, support and environmental relationships, space relationships, or functional relationships. For example:

•• Support relationships refer to the external services that must be supplied to shipborne systems in order that these systems can satisfactorily perform their intended function (e.g., they need cooling water, electrical power, etc.). "Environmental" relationships refer to the limitations/constraints of shipborne systems in areas such as: magnetic fields, temperature, humidity, shock, vibration, ice, wind, precipitation, noise, degree of enclosure, and salt spray.

•• Although not strictly a matter of performance, any position or distance requirements for a shipborne system/equipment relative to the ship or other system/equipment as may be necessary to satisfy the intended use or operational requirements must be specified. For example: external connections and dimensions/configuration (length, width, diameter, height, and associated tolerances); projections and door swings; tray or module pullout space or removal areas; areas to be clear of and areas provided for pipes, ducts, and cabling; areas to remain clear for maintenance access, and access ports or doors; operational areas and arrangements or, orientation; bolt-hole patterns, mounting hole sizes, mounting pad sizes, thread size, and bracing requirements, if any; weight and location of the center of gravity, finish and/or the characteristics of the material to which the system/equipment is to be in contact.

·· In the electrical/electronic area, functional considerations pertain to intelligence signals flowing between the ship and potential targets, or, through shipborne system/equipment interfaces. In the mechanical area, functional considerations pertain to the dynamic load - transferring capabilities between shipborne systems or between shipborne systems and the ship. The primary interest in the electrical/electronic area is functional integration of the combat system. Performance requirements are assigned and allocated to the various major components of the combat system in such a way as to meet operational requirements and achieve functional integration. It can be surmised, for example, that the power and range of a tracking radar of a surface ship definitely limits the capabilities of the combat system. It is very important, therefore, to assign performance requirements to the tracking radar which will allow the combat system to meet those operational requirements pertaining to range (e.g., "the surveillance system must be capable of detecting and tracking air targets traveling at mach 3, up to 400K yards in range and 100K feet in altitude"). In the mechanical area, some shipborne systems, such as missile launchers and missile handling systems, perform non-static functions by engaging or mating with other areas. In these cases interface constraints are expressed in terms such as: configuration/dimensions and tolerances for all non-permanent mating surfaces; weight and CG location of loads

imposed as a result of engagement/mating and amount and direction of forces required to move and to engage or disengage; specific areas upon which no load may be imposed; overall envelope and direction and amount of motion required for engagement or disengagement; and, type, weight, hardness, linear expansion and susceptibility to erosion of the mating or engaging surfaces.

For this hypothetical example, imagine the interface between the Poseidon missile and the Trident submarine. This is a very complex interface between two systems which have not been built before. And, to complicate matters, the two systems are under the cognizance of two different organizations. The point I wish to make again is that the interface area provides fertile ground for TPM. For this example then let's consider a simple parameter, P_1, within the interface and assume it is defined as a function of w, that is, $P_1 = f(w_1, w_2 \ldots w_n)$.

The steps in the TPM process were described in pages 7, 8, and 9. I have already completed the first step by selecting the parameter, P_1, for measurement. The next steps are to develop subjective probability distributions for $w_1, w_2 \ldots w_n$, the inputs, by making inquiries of design personnel and to simulate values for P_1. This process is described on pages 8 and 9 and in reference (4) so will not be repeated here. It is important to note, however, that these simulations should

be scheduled to coincide with important events during the life of the project, such as preliminary design review. It is also important to note that target or baseline values of P_1 must be selected as a basis for w_1, $w_2 \ldots w_n$ and the subjective probability distributions. For example: each value assigned to a TPM parameter may be a specification or contractually specified value; a design goal determined by engineering or project management to represent the best attainable performance; or the value predicted for measurement at a specified verification event [this is a "planned" value and it may be different at each event or it may remain constant with time -- a plot of planned values versus time is known as the "profile" -- a sample profile is shown on page A-15 of Appendix A.]. A control value which represents the most likely limit or tolerance for a planned parameter at a specified verfication event must also be developed, see page A-15.

The last steps are tracking, variance analysis if required, and reporting if required to bring a problem to the attention of management. Here again, this process was described on pages 9 and 10 and will not be repeated here. Reporting should be tailored to the needs of the project. Variance analysis, or compatibility analysis in the case of interfaces, must be performed as required and, if necessary, trade-offs must be made to assure compatibility.

Conclusions

According to reference (6): Lord Kelvin is quoted as saying, "When you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind." In my opinion then the notion of TPM appears to be very attractive as a tool to measure technical progress, and to identify and control risk. And it appears to me to be a worthwhile endeavor when we are in the design stages as well as when we have developmental hardware available for test.

The benefit of implementing a TPM system should certainly exceed the cost when technical risk is apparent. And, what is the cost? I cannot provide any rules of thumb to answer this question. It would depend on many things such as the number of parameters being tracked and reporting requirements. Cost must be negotiated in each case. My major point here is that the TPM system seems to be worth the effort in developmental programs.

There are no textbooks dealing with TPM and trade-offs. The best source of detailed guidance for TPM however, appears to be reference (3). There are no all encompassing, simple references pertinent to trade-offs. It is hoped that the general guidance provided in this paper will satisfy the needs of a number of project managers.

ANNOTATED BIBLIOGRAPHY

1. MIL-STD-499 (USAF), System Engineering Management

   This standard provides system engineering management requirements which can be tailored to project needs. It introduced the concept of TPM and includes a description of requirements applicable to TPM and trade-off studies.

2. CODSIA, Need Use Analysis, Systems Engineering

   This study emphasized the need for a integrated systems engineering effort. It was sponsored by DDR&E in conjunction with the Council of Defense/Industry Associations.

3. SPACE DIVISION, NORTH AMERICAN ROCKWELL CORPORATION, Technical Performance Measurement Guide

   This guide provides criteria and recommended techniques which may be used to implement established TPM requirements.

4. TIMSON, F.S., Measurement of Technical Performance in Weapons System Development Programs: A Subjective Probability Approach. Prepared for ARPA by the Rand Corporation, December 1968.

   This paper presents an exploratory effort to develop the framework of a procedure for the collection and analysis of data on uncertainty and progress regarding technical performance in weapon system development.

5. UCLA, SCHOOL OF ENGINEERING AND APPLIED SCIENCE, Case Studies in Computer Simulation, TRANSIM, Activity Network Analysis of Ship Acquisition Project Management. Prepared for the Office of Naval Research by UCLA, September 1970.

   This report describes a Monte-Carlo-type computer simulator especially applicable to solving problems associated with ship acquisition.

6. TRW SYSTEMS GROUP, Technical Performance Measurement, Presented by Giyora Doeh at the ASPR Institute Seminar on System Engineering Management, Los Angeles, California, December 4, 1969.

   This presentation covers a TPM system established by TRW, Redondo Beach, California.

7. U.S. ARMY SAFEGUARD SYSTEM COMMAND, Technical Specification 705-435, Site Defense of Minuteman, Technical Performance Measurement, March 1972.

This specification describes the TPM system used by Martin Marietta and McDonnell/Douglas in the SPRINT Missile program, a part of Safeguard.

8. SPACE DIVISION, GENERAL ELECTRIC CO., Technical Performance Measurement (TPM), Guidelines for a Compliant System. Presented by Mr. A.E. Miller at the ASPR Institute Seminar on System Engineering Management, Los Angeles, California, December 4, 1969.

This presentation covers a TPM system, compliant with MIL-STD-449, developed by the Valley Forge Space Division, General Electric Co.

9. NAVSHIPS NOTICE 4121 dated 6 March 1972, Specifications Control Board and Cost-Benefit Analysis Procedures.

This notice provides the basic cost-benefit analysis procedures used by the Naval Ship Systems Command.

10. D.R.J. White, D.L. Scott, and R.N. Schulz, POED - A Method of Evaluating System Performance, IEEE Transactions on Engineering Management, December 1963.

This article described POED (Performance Organization for Evaluation and Decision) which is an evaluation and decision technique which permits computing performance of a device, equipment, system or system complex; compares and scores this performance against requirements or value judgements representing user's needs; and organizes results in a useful manner so that assessment of value is readily achieved.

11. CDR. B.L. Potts, Equipment Readiness, Working paper No. 36 ASW Force Level Study.

This paper describes a computer model which was constructed for use by the ASW Force Level Study.

APPENDIX A

SAMPLE TPM TRACKING AND OUTPUT REPORTS

TABLE I

PROBABILITY DISTRIBUTIONS FOR SPEED OF HYPOTHETICAL SHIP AT THREE-MONTH INTERVALS DURING DEVELOPMENT

V \ time	0 mo	3 mo	6 mo	9 mo	12 mo	15 mo	18 mo	21 mo
16 knots	.15	.20	.15	.10	.05	.05	.05	.00
17 knots	.20	.30	.30	.30	.30	.25	.20	.20
18 knots	.45	.25	.30	.35	.35	.40	.50	.55
19 knots	.10	.25	.25	.25	.25	.25	.20	.20
20 knots	.10	.00	.00	.00	.05	.05	.05	.05

TABLE II

INFORMATION FOR EVALUATION OF PROGRESS AND STATUS OF HYPOTHETICAL SHIP DEVELOPMENT PROJECT SHOWN IN ABOVE TABLE

Item \ time	0 mo	3 mo	6 mo	9 mo	12 mo	15 mo	18 mo	21 mo
$p(V) > 17$ (knots)	.75	.80	.85	.90	.95	.95	.95	1.00
$p(V) > 19$ (knots)	.00	.00	.00	.00	.05	.05	.05	.05
$\mu(V)$ (knots)	17.5	17.6	17.7	17.8	17.9	18.0	18.0	18.3
$\sigma(V)$ (knots)	.7	.6	.5	.4	.4	.3	.2	.1
Dollars Consumed (Millions)	negligible	6	10	12	13	13	15	15
Time Interval (mo)	0	3	3	3	3	3	3	3
Dollars Remaining (Millions)	100	94	84	72	59	46	31	16
Time Remaining (mo)	24	21	18	15	12	9	6	3

where, $\mu(V)$ is the mean value of speed and $\sigma(V)$ is the standard deviation

PROBABILITY OF MEETING OR EXCEEDING MINIMUM REQUIREMENTS AND PROBABILITY OF BEING WITHIN MAXIMUM AND MINIMUM REQUIREMENTS LIMITS

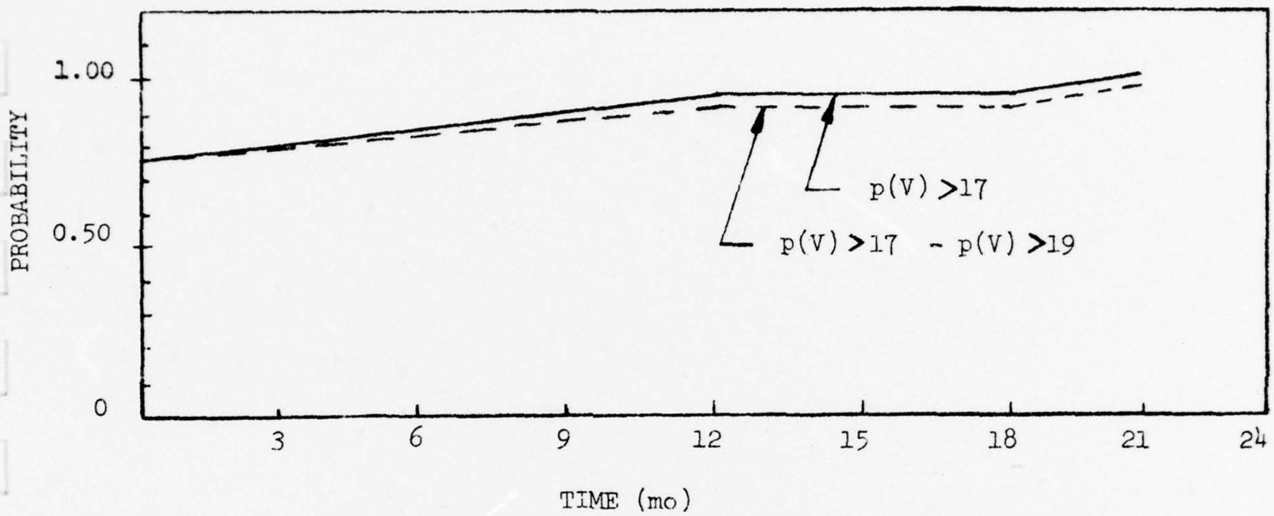


FIGURE 1

MAGNITUDE OF STANDARD DEVIATION AT THREE-MONTH INTERVALS

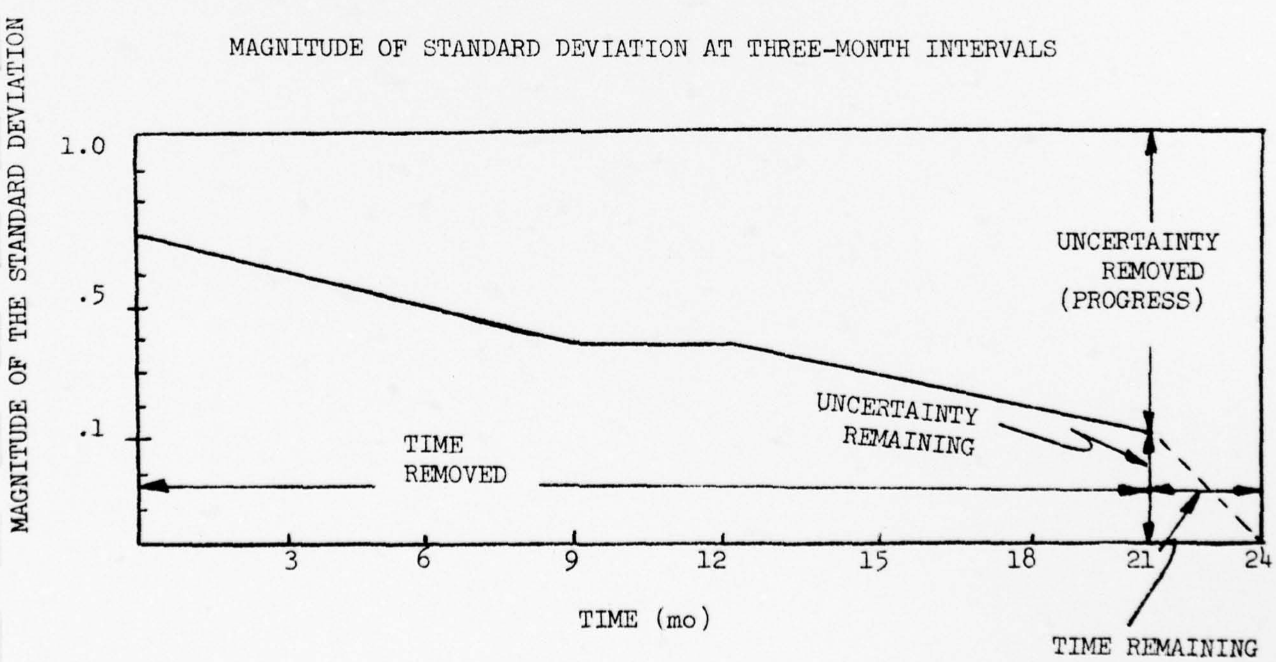


FIGURE 2

TPM [illegible]TUS SUMMARY

ALL SYSTEM PERFORMANCE CHARACTERISTICS

TAP NO. ______________ REV. ________ PROGRAM ______________

WBS ITEM ______________ PMSA NO. ______________

WBS NO. ______________ DATE ______________

WORK PKG MGR ______________ PAGE ______ OF ______

WORK PKG NO. ______________

PREPARED BY: ______________

SYSTEM PERFORMANCE CHARACTERISTICS							
TITLE	PARAMETER UNITS	PLANNED VALUE	CURRENT VALUE	CURRENT VARIANCE	ALLOWED VARIANCE	TRACKING RESPONSIBILITY	REMARKS
C.E.P.	FT.	1000	2000				
REACTION TIME	MIN.	10	20				
RECOVERY TIME	MIN.	5	15				
RANGE	N.M.	6000	5000				
ETC.							

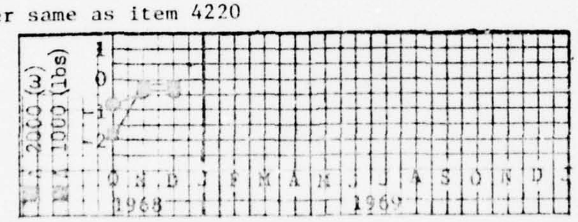
SAMPLE FORMAT, SYSTEM PERFORMANCE CHARACTERISTICS STATUS

Figure (3)

CME PARAMETER PROGRESS SUMMARY December 1968

ITEM	PARAMETER	SPEC. REF.	SPEC. LIMITS	DATA	VARIANCE	DATA REF.	FACTOR	WBS. REF.
1000	WEIGHT	EQ8-35; 3.1.3	10.0 lbs max	9.62 lbs	-0.38 lbs	Calc. 12/68	- -	11
1100	Propellant	EQ8-35A; 3.1.3	0.50 lbs min	0.50 lbs	0	Report No.10	÷ 0.88 (b)	20
1200	Thrustor	- -	- -	0.15 lbs	0	Report No.10	x 2	10
1300	Feed System	- -	- -	2.35 lbs	0	Report No.10	- -	20
1400	P&SC	(a)	4.00 lbs max	4.05 lbs	+0.05 lbs	Report No.11	- -	13
1500	Structure	- -	- -	2.35 lbs	- -	Est. 12/68	- -	23
2000	POWER (ac)	EQ8-35A; 3.2.2.1	7.0 w max	6.8 w	-0.2 w	#7039 Pg 20(c)	- -	11
2100	Beam	- -	- -	0.24 w	0	Est. 12/68	÷ 0.20 (c)	13
2200	Neutralizer	- -	- -	0.9 w	- -	#4905 Pg.59	(c)	10
2300	Heater	- -	- -	1.7 w	- -	#7039 Pg 20(c)	÷ 0.65 (c)	28
3000	POWER (dc)	EQ8-35A; 3.2.2.2	5.0 w max	5.0 w	0	EQ2-134A;4/67	- -	20
4000	THRUST @900 sec I_{sp}(d)	EQ8-35A; 3.3.1	8.0± 1.0 μlb	8.0±1.0 μlb	0	Calc. 8/68	- -	11
4100	Beam Current	- -	- -	36 μA	- -	Report No. 4	(e)	11
4110	P&SC Regulation	EQ3-157;3.2.1.8.5.2	36.0± 1.0 μA	36.0±1.0 μA(f)	0	Report No.11	- -	13
4200	Mass Flow Rate	- -	- -	4.0 μgm/sec	- -	Report No. 4	(e)	11
4210	Temperature	- -	- -	30 °C	- -	Report No. 4	(e)	11
4211	P&SC Regulation	(a)	30 ± 0.5°C	30 ± 0.6°C	±0.1 °C	Report No. 11	- -	13
4220	Feed Pressure	- -	- -	50 torr	- -	Report No. 4	(e)	11
4221	Feed System	- -	50 ± 10 torr	50 ± 10 torr	0	Report No. 12	- -	20
5000	THRUST @750 sec I_{sp}(d)	EQ8-35A; 3.3.1	4.0± 1.0 μlb	4.0±1.0 μlb	0	Calc. 8/68	- -	11
5100	Beam Current	- -	- -	18 μA	- -	Report No. 4	(e)	11
5110	P&SC Regulation	EQ3-157;3.2.1.8.5.2	18.0± 1.0 μA	18.0±1.0 μA	0	Report No. 11	- -	13
5200	Mass Flow Rate (g)	- -	- -	2.5 μgm/sec	- -	Report No. 4	(e)	11
5210	Temperature	- -	- -	25 °C	- -	Report No. 4	(e)	11
5211	P&SC Regulation	(a)	25 ± 0.5°C	25 ± 0.6°C	±0.1 °C	Report No. 11	- -	13
6000	LIFETIME	EQ8-35A; 3.3.3	1000 hr(h)	167 hr(k)	-833 hr	Report No. 16	- -	11
6100	Thrustor	- -	- -	2,400 hr	- -	(m)	- -	--

NOTES:
(a) Spec. revision req'd
(b) Calculated expulsion efficiency = 88%
(c) P&SC circuit efficiency = 20% for beam power, ~ 100% for neutralizer, = 65% for heater. 2.1 w idling power measured with beam, neutralizer and heater off.
(d) Nominal I_{sp}
(e) Use calibration data, Report No. 4
(f) Extrapolated data
(g) Feed pressure parameter same as item 4220
(h) 10,000-hr design life
(k) Without neutralizer
(m) AFAPL life test



REMARKS:
(1) Atmospheric permeation of feed system elastomers prevents practical propellant storage in present configuration. Mk II feed system task is in progress (Report No. 17).
(2) Valve diaphragm tends to stick to seat. Plunger to diaphragm adhesives are being evaluated. (Report No. 17).
(3) 1300-hrs accumulated operating time on 2 systems (Report No. 16).
(4) 230-hrs thrustor lifetime with neutralizer (Report No. 7).
(5) 3600-hrs accumulated thrustor lifetime (m)

Figure (4)

TPM ACTION ITEM REPORT

ACTION ITEM REPORT NR.________ ISSUE NR.________ ORGANIZATION DATE________

WBS CODE____ ________ DESCRIPTION________

PARAMETER NR.________ DESCRIPTION________

SPECIFICATION REQUIREMENT VALUE (LIMIT)________ UNITS________ VERIFICATION POINT________

TEST/PLANNED VALUE________ DEMONSTRATED VALUE________ CLASS________

IMPACT

PERFORMANCE________

____

SCHEDULE________

____

COST________

____

DISCUSSION________

____

PREP. BY________ ISSUE DATE________

GOVT ACT________ APPROVALS________

Figure (5)

DATA ITEM DESCRIPTION

1. TITLE	2. IDENTIFICATION NO(S). AGENCY	NUMBER
Technical Performance Measurement Report		(U)S-102-1

3. DESCRIPTION/PURPOSE

To provide visibility to the program/project manager on the state of engineering accomplishment toward the contract requirements as compared with planned and required values. Provides a basis for projecting needed supporting efforts.

4. APPROVAL DATE

11 August 1969

5. OFFICE OF PRIMARY RESPONSIBILITY

AFSC

6. DDC REQUIRED

8. APPROVAL LIMITATION

Pending publication in the ADL. (DRAFT)

7. APPLICATION/INTERRELATIONSHIP

These data are related to the design requirements (Part I of the specification) for the Configuration Item (CI) and to its critical elements and design parameters. The reportable CI elements and parameters to be included in this report will be those listed in the System Engineering Management Plan incorporated as a contract requirement and will be identified on the DD Form 1423 either by attachment or reference to the SEMP. This DID will normally be used only when MIL-STD-499 is a contractual requirement; otherwise, DD Form 1664 S-102 should be used. Should this DID be preferred to S-102, when MIL-STD-499 is not a contractual requirement, the task effort for generating this data must be included in the contract work statement.

9. REFERENCES (Mandatory as cited in block 10)

MIL-STD-499

MCSL NUMBER(S)

10. PREPARATION INSTRUCTIONS

1. The contractor shall prepare a TPM report(s) on designated parameters. The DD Form 1423 will specify whether a particular report will cover all parameters of a system element, and individual parameter, or selected groupings of parameters.

2. For each parameter selected for TPM reporting, reports shall include:

a. The demonstrated value, planned value, and demonstrated variance for the design at the time of the TPM, plus the current estimate, the current specification requirement and the predicted variance for the end product. Determination of the current estimate shall be based on the demonstrated value and the changes to the parameter value which can be attained within the remaining schedule and cost baseline The format shall be as described in paragraph 3 below.

b. Status of the configuration design and discussion of design and engineering investigations (e.g. experiments and tests performed) and analyses which support the demonstrated value, and discussion of the technical effort which supports the

Preparation Instructions (Continued)

predicted profile leading to the current estimate.

c. Variance Analysis to include discussion of design, development, and/or fabrication problems encountered which cause demonstrated or predicted performance outside the planned tolerance band. When this occurs a revised planned value profile will be presented ~~developed~~ as shown in Figure 2. The contractor will report impacts on higher level parameters, on interface requirements and on system cost effectiveness if appropriate. For performance deficiencies, alternate and proposed recovery plans and associated configuration changes will be reported with the performance, cost, and schedule implications of each. For performance in excess of requirements, possibilities for reallocation of parameter requirements and budgets will be reported.

d. Drawings, layouts, graphs, etc. as appropriate to support the above.

e. When discussion called for by this data item is covered by another report required by the DD 1423, reference thereto in lieu of repetition shall be made.

3. The performance comparison will be in tabular and graphical form, with the tabulation as shown in Figure 1 and the graph as in Figure 2. The system elements and reportable parameters/parameter planned-value-profiles as exemplified in Figures 1 and 2 will be defined either in the SEMP, the task description on the CI-subsytem, or as ~~and will be~~ an attachment to the CDRL.

4. Definitions:

a. System Element. A discrete portion of a system. A product element of the Work Breakdown Structure (WBS) at any level is a system element.

Preparation Instructions (Continued)

b. Planned Value. The anticipated value of a parameter at a given point in the development cycle. A plot of these versus time is known as the Planned Value Profile. In addition to the planned value profile, it may be desirable to indicate a range of acceptable values versus time. When this range is shown, it is known as a tolerance band.

c. Demonstrated Value. The demonstrated value of a technical parameter is the value which is estimated or measured in a particular test and/or analysis.

d. Specification Requirement. The value or range of values contained in a contractual performance specification or allocated from such a specification, with a verification requirement for the end product.

e. Current Estimate. The value of a parameter predicted for the end product of the contract.

f. Demonstrated Technical Variance. The difference between the Planned Value and the demonstrated value of a parameter.

g. Predicted Technical Variance. The difference between the Specification Requirement and the Current Estimate of the Parameter.

TECHNICAL PERFORMANCE MEASUREMENT COMPARISON

System Element	Parameter	This TPM (Date or Milestone) Demonstrated Value	Planned Value	Demonstrated Variance	Current Estimate	End Product Specification Requirements	Predicted Variances
ENGINE	SLS Thrust, lbs	26000	28000	-2000	29000	30000	-1000
(Note: In this case, the CI/Subsystem is the "System Element")	Weight, lbs	5400	5500	-100	4900	5000	-100
	SFC, lbs/Hr-lb	.045	.05	+0.005	.04	.04	-0-
THRUST	Compressor Pressure Ratio	7.8:1	7.5:1	+0.3	8:1	8:1	-0-
	Turbine Efficiency (%)	87	85	+2	88	87	+1

AEGIS TECHNICAL ACHIEVEMENT SUMMARY

EQUIPMENT DESCRIPTION:	Weapons System, MK 7 MOD 0, AEGIS (WS-7833(R)/4A)	REPORT MONTH:	January
WBS KEY: 01-001/000	RESPONSIBLE ENGINEER: J. T. Nessmith	DATA AS OF:	31 January 1973

	ITEM	KEY PARAMETER	SPECIFICATION VALUE	10/70	2/72	10/73	3/74	1/74	1/74	9/74	3/75	9/75		SCHEDULE DATES
				A	B	C	D	E	-	F	8	-		CONTRACT MILESTONES
				Last C&L PDR	Last C&L CDR	EDM-1 Cat II LBTS	EDM-1 Cat II AVM-1	EDM-3 Cat I & CAR	Navy Demo AVM-1	EDM-3 Ckout AVM-1	Contr Tech Eval	Navy Tech Eval		PERFORMANCE ACHIEVEMENT EVENTS ↓ REMARKS
(U)	21	System Inherent Availability (Ai)	.96	✓ 0.992	✓ *.985									Current CDRL #144 evaluation: .98
(U)	22	System Operation Availability (Ao)	.925	-	- .958									Current CDRL #144 evaluation: .95
(U)	23	C&L System MTBF	50 hrs	✓ 92.3	✓ 70									Current CDRL #144 evaluation: 60 hrs.
		MILESTONE NUMBER →		10105	10120	16800	(TBS)	16885	16816	16826	16829	70007		
				10/70	2/72									← COMPLETION DATES

☑ - PERFORMANCE ACCEPTABLE
☒ - PERFORMANCE PROBLEM

FOOTNOTES: *Evaluations based on RCA selected hardware criteria for satisfactory performance as reported in R&M Anal Rpts, CDRL 147, submitted for CDR's.

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AEGIS TECHNICAL ACHIEVEMENT SUMMARY

EQUIPMENT DESCRIPTION:	Radar Set Group, OY- /SPY-1 (WS-9871/4)	REPORT MONTH:	January
WBS KEY: 03-062/002	RESPONSIBLE ENGINEER: H. B. Grossman	DATA AS OF:	31 January 1973

	ITEM	KEY PARAMETER	SPECIFICATION VALUE	6/70	9/70	10/70	1/71	4/71	9/71	1/72	12/72	12/72	6/73	SCHEDULE DATES
				PDR	Feed HiPwr Test	CFA Tube Demo	SP Dsgn Rvw	Phase Shftr & Drvr Test	CFA Qual Test	Exec Panel CDR	Xmtr Cat I Compl	Ant Cat I Compl	SPY-1 Cat I Compl	PERFORMANCE ACHIEVEMENT EVENTS ↓ REMARKS
(U)	11	MTBF (hrs)	75	134 ✓	- -	*148 ✓	- -	- -	*90 ✓	90 ✓	- -	- -		
(U)	12	MTTR (System) (hrs)	≤ 1.5	.94 ✓	- -	*.64 ✓	- -	- -	*1.4 -	1.4 ✓	- -	- -		
(U)	13	RF Power Output, High Power (Mw)	4	- -	4.2 ✓	4.0 ✓	- -	4.0 -	5.18 ✓	5.18 ✓	- -	- -		
		MILESTONE NUMBER →		13003	23034	33055	23120	23041	32333	N.A.	33326	23052	23300	
				6/70	9/70	10/70	2/71	6/71	9/71	1/72	12/72	12/72		← COMPLETION DATES

✓ - PERFORMANCE ACCEPTABLE

☒ - PERFORMANCE PROBLEM

FOOTNOTES: *Interim evaluations made 10/70 and 12/71 - not associated with PAE's.

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AEGIS TECHNICAL PER..RMANCE INDEX

EQUIPMENT DESCRIPTION: Radar Set Group, OY- /SPY-1 (WS-9871/4)	REPORT MONTH: January 1973
WBS KEY: 03-062/002 — RESPONSIBLE ENGINEER: H. B. Grossman	TPI: 90.0

	ITEM	KEY PARAMETER	SPECIFICATION VALUE	SPECIFICATION WEIGHT FACTOR (SWF)	CURRENT CONFIDENCE FACTOR (CCF)	3/72 Rcvr Shftr Drvr Test	4/72 HVPS Elec Perf Test	5/72 BSC Cabnt Ckout	6/72 BSC Perf Qual	7/72 FPA 1 + PDD 2 Debug	8/72 CFA Env Qual	9/72 Start SP Intgr Tests	10/72	11/72	12/72 Ant & Xmtr Cat I Tests	1/73	
(U)	11	MTBF (hrs)	75	15	.9	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	
(U)	12	MTTR System (hrs)	≤ 1.5	6	.9	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	
(U)	13	RF Power Output, High Power (Mw)	4	5	.9	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	
				100		90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	

TECHNICAL PERFORMANCE INDEX= $\sum_{1}^{n} [(SWF)(CCF)]$

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AEGIS TECHNICAL PERFORMANCE INDEX

EQUIPMENT DESCRIPTION: Weapon Direction System, MK 12 MOD 0 (WS-9874/4A)		REPORT MONTH: January 1973
WBS KEY: 03-012/002	RESPONSIBLE ENGINEER: E. L. Willey	TPI: 88.0

	ITEM	KEY PARAMETER	SPECIFICATION VALUE	SPECIFICATION WEIGHT FACTOR (SWF)	CURRENT CONFIDENCE FACTOR (CCF)	3/72 WCCP TI Mod 1 Test	4/72	5/72 EDM-1 Mods& ATEP Integ	6/72	7/72	8/72 Start WCCP Tests	9/72	10/72 Start PH II WCCP Test	11/72	12/72	1/73	
(U)	11	MTTR (System) (hrs)	1.0	6	.9	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	
(U)	12	MTBF (hrs)	800	10	*.7	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	
				100		84.5	88.0	88.0	88.0	88.0	88.0	88.0	88.0	88.0	88.0	88.0	

TECHNICAL PERFORMANCE INDEX= $\sum_{1}^{n}\left[(SWF)(CCF)\right]$

*See Problem Analysis Report Attached.

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Problem Analysis Report

Equipment Description: Weapon Direction System, MK 12

1. WDS segment MTBF of 800 hours is in some doubt due to a reduced estimate of reliability for the Signal Data Converter (SDC) based on prediction and limited field data. Continued assessments will be made as Tartar field data is received and analyzed. Potential major design changes planned for the MK 81 development have been deferred pending RCA/NAVY action.

ILLUSTRATION OF A TPM

AT TIME (MILESTONE) A

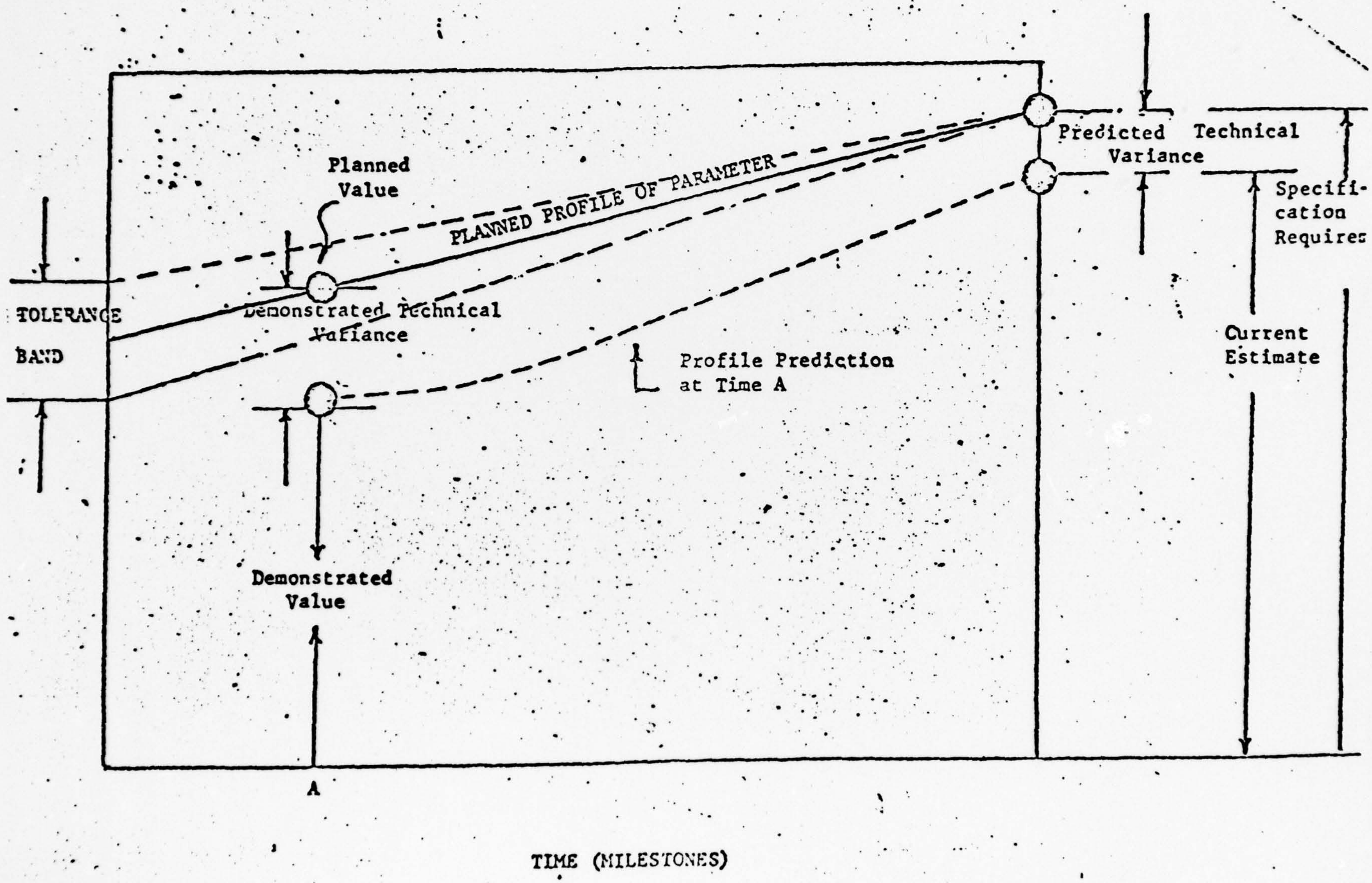

Figure 2

TRADE-OFF REPORT OUTLINE

____
Date

1. ______________________ Ship Project   1.a. ______________________ Life Cycle Phase

2. Problem to be corrected/objective of the study

3. Facts bearing on the study/reference documentation

4. Assumptions and Criteria

5. Alternatives considered (advantages/disadvantages)

6. Relative Ranking of Alternatives/Conclusions

7. Recommended Action